APPLICATION OF RETROFITTING ANALYSIS TO AMMONIA PRODUCTION PLANTS

DR. NEERAJ K. CHAVDA
Associate Professor
Mechanical Engineering Department, A. D. Patel Institute of Technology
Email: neeraj_chavda@yahoo.com

ABSTRACT

Retrofitting analysis of an existing network of chemical plant is carried out to ensure the minimum requirement of utilities, heat transfer area and total cost. Since the development of various retrofitting techniques, it has been applied to various chemical plants and enjoyed the success. Ammonia is a basic chemical for production of (1) nitric acid which is used for production of dyes, fibres, plastic and explosives and (2) ammonium nitrate a fertilizer. Ammonia is produced in plants which were installed before the introduction of pinch technology. The objective of the study is to critically study the development of various retrofitting techniques and their applications to various types of plants. Ammonia production plants are highly energy consuming plants. Therefore, more emphasize is given to the application of retrofitting analysis to ammonia production plant. It has been found that out of total fifty-five publications available in open literature related to the retrofitting analysis of a chemical plant; only 18% are in the field of application of retrofitting analysis to ammonia production plants. This reveals the fact that retrofitting analysis can be implemented to various ammonia production plants to reduce the energy consumption of the plant.

Keywords: Retrofitting, Chemical Plant, Ammonia Plant, Pinch Technology.

1. INTRODUCTION

In a chemical or fertilizer manufacturing units, feed has to pass through the sequence of heat exchangers. The inlet temperature of the stream to the next heat exchanger depends on the previous heat exchanger design, effectiveness and process data. In such cases, even if all the heat exchangers are designed accurately, they may not work with their proper effectiveness and may result in increase of total cost of the manufacturing unit. The problem is known as the problem of heat exchanger network synthesis in a chemical plant. Briefly the problem of heat exchanger network synthesis (HENS) may be defined as the determination of a cost-effective network to exchange heat among a set of process streams, where any heating and cooling not satisfied by exchange among these streams must be provided by external utilities (e.g., steam, hot oil, cooling water, refrigerants etc.). Additional constrains like plant layout, safety, flexibility, operability and controllability must be accounted for. Pinch technology developed by Linnhoff [1] is one of the tools for solving the above problem. It recognizes the necessity of setting targets, i.e., predicting what is the best performance that can be possibly be achieved by the process, before actually attempting to achieve it. Thus, targeting allows the process engineer to determine the minimum utility requirements, area, number of unit, number of shell and cost prior to actual design of a heat exchanger network.

Pinch analysis is the method to design the heat exchanger network prior to set up any chemical or fertilizer manufacturing unit. The big question comes to any layman's mind is that "*What about the chemical plant*" that have been designed and set up without incorporating the fundamentals of pinch analysis. The problem is known as the problem of modification of existing chemical plant. Modification of existing plants can be achieved by various retrofitting techniques. The various retrofitting techniques adopted so far are discussed and compared in the paper.

2. DEVELOPMENTS IN RETROFITTING ANALYSIS

The concept of energy saving and energy conservation came into existence in early 80's. Willem van Gool [2] has discussed about the fundamental aspects of energy conservation policy. According to him, issues involved in energy deficit should be fundamentally analyzed. Information transfer, more intensive use of data, and good housekeeping can all contribute to reduced energy use. The major choice, however, is between producing the present mix of materials, commodities and services more efficiently or decreasing demand for them. The first option is referred to as the "technical fix", and the second one as "change of lifestyle". If the first option fails, changes in life-style might become mandatory. The time scales involved pose the major problem to achieve conservation by means of a technological fix. An increase in the price of energy will lead to higher capital investments in accordance with the economic lifecycles in the different sectors. For applications with a short life-time, such as in the chemical plant, energy conservation will mainly take place through the modification of the chemical plant i.e. retrofitting.

To achieve the heat recovery in an existing plant, some of the investigators have critically studied the overall flow diagram of the plant and found some modifications based on their experience. Boland [3] have achieved the modification of ICI plant by matching certain streams that seemed likely candidate and saving energy in the plant. Linnhoff and Vredeveld [4] have carried out retrofitting analysis of Union Carbide plant using pinch technology. Tjoe and Linnhoff [5] have explained the application of pinch technology for process retrofits. David A. Reay [6] has also considered the problem of energy conservation by comparing two alternatives viz. (1) to redesign the chemical plant or (2) to retrofit the chemical plant. According to him, the sectors where energy usage is significant, conservation measures may be implemented without recourse to extensive plant or building redesign. This applies to heat recovery in the industry. For a design engineer, however, has considerably greater incentive to redesign his process when faced with the opportunity to incorporate heat recovery equipment. Retrofitting an existing chemical plant is another alternative. Both can lead to cost savings, the second-one generating a more rapid return of possibly lower magnitude. Both provide the engineer with challenges to his technical and managerial skills.

Pinch technology developed by Linnhoff [1] can also be applied to retrofit the existing plant. Linnhoff and Witherell [7] have carried out retrofitting analysis of an ethylene plant using pinch technology. Jones et al. [8] have studied practical synthesis techniques for retrofitting heat recovery systems. According to them, computer search technique can be used to choose from a number of simulated maximum energy recovery networks with the most favorable economics and with minimal change. While Lee et al. [9] have applied the pinch technology to retrofit a refinery.

Using mathematical programming techniques, network modification can also be achieved. Ciric and Floudas [10] have proposed mixed integer linear programming model for retrofit at a level of matches based on a classification of the possible structural modifications. While Yee and Grossman [11] have proposed mixed integer non-linear programming model for retrofitting an existing plant. Lakshmanan and Bañares-Alcántara [12] have described visualiasation tool for developing retrofit solutions by inspection. According to them this method relies heavily on the ingenuity of the designer but has proved to be very flexible-handling a wide variety of problem formulations.

Based on above review, retrofitting techniques can be classified into four broad categories like computer search, mathematical programming, inspection and pinch technology. The computer search method may not prove efficient in many cases due to three reasons: The element of chance in hitting or missing the best network, the large amount of computational effort involved in simulating many networks and the difficulty in retrofitting to identify a design having a structure reasonably close to the existing one and simultaneously transferring zero heat across the pinch. The methods of retrofitting by inspection and computer search carry the potential risk of the network not being the optimum. While the use of mathematical programming makes strong computational demands. Retrofitting by pinch analysis provides a promising alternative.

3. REVIEW OF APPLICATION OF RETROFITTING

Based on the development of different retrofitting techniques to minimize the energy requirements of the chemical plant, many investigations have been carried out after the year 1990 to retrofit the existing chemical plant. In the present study, these investigations are grouped as retrofitting technique applied to chemical plant (batch type and continuous type both), alternative approach for retrofitting analysis and retrofitting of an existing ammonia production plant.

The review of retrofitting of an existing ammonia production plant is separated from chemical plant due to the fact that ammonia is one of the largest volume industrial chemicals in the world and is essential to meet the food production of growing population. It is the highly energy consuming product requiring from 6 to 12 Gcal/MT of ammonia depending on the raw material used and the process route adopted. Since the development of the Haber-Bosch process for industrial Ammonia synthesis, the energy requirement of Ammonia has been continuously reduced from approximately 20.335 Gcal/MT of NH_3 in early 1950s to a current level of about 6.459 Gcal/MT of NH_3.

4. APPLICATION OF RETROFITTING TO CHEMICAL PLANTS

Chemical plants are broadly classified as batch type plant and continuous plant. In batch type chemical plant, more than one product is manufactured using the same equipment one after another as per the market demand. In this type of chemical plan, plant layout is not fixed. While, in continuous type chemical plant, only one type of product is manufactured and plant layout is product type. Retrofitting analysis can be applied to both the types of plants.

4.1 Batch Type Chemical Plant

Antonio Espuña and Luis Puigjaner [13] have addressed the problem of retrofitting of multiproduct batch type or semi-continuous chemical plant. Their procedure calculates new units sizing in order to integrate them into the existing plant structure and maximize plant profit, taking into account capital investments and other production costs. J. Corominas et al. [14] have systematically studied an energy saving grass-root design and retrofitting technology based on process integration for the batch mode of operation. They have identified the solution to the changeover product problem in order to achieve a feasible and optimized heat exchange network design for multiproduct batch plants. They have presented a new methodology which is based on: (a) the campaign-mode of plant operation, (b) the study of energy integration for each campaign. They have presented the algorithm based on the test case-studies.

4.2 Continuous Type Chemical Plant

Ciric and Floudas [15] have presented retrofit approach for heat exchanger network. They have presented two stage procedures for optimal redesign of existing heat exchanger networks. In the first stage structural modifications have been proposed by using MILP model and in the second stage superstructure is proposed based on the information generated in the first stage. They have demonstrated the procedure using three example problems. Wang and Chen [16] have proposed rapid analysis method for heat recovery in industrial plants. S. Ahmad and G. T. Polley [17] have presented systematic procedure for the debottlenecking of heat exchanger networks of crude unit using pinch technology to predict the near-minimum energy and capital requirements before retrofitting the network for increased throughput.

Z. Fonyo et al. [18] have extended hierarchical decision procedure for retrofitting problems based on the experience. They have selected case studies based on the publication of the Fribourg Group of German and Swiss chemical firms. They have evaluated the cases and used to refine, improve and extend the hierarchical synthesis procedure for waste minimization to process retrofitting. Nilsson and Sunden [19] have analyzed crude distillation system using pinch technology and he MIND method. They have optimized the HEN using the pinch technology first and the results from the pinch analysis are given as input to the MIND optimization. Their result showed that the steam demand from the boiler unit in the energy supply part of the system can be reduced by 20 % in the optimized HEN and by 21 % when a heat pump is added to the system. Marechal et al. [20] have employed Effect Modelling and Optimization (EMO) model to optimize the energy efficiency of the methanol production process. The stated method allows identifying different ways of improving the energy efficiency of the process. They have found that classical methane conversion of 60 % can be increased up to 93 % when they have transformed the net mechanical power produced into methane savings at the country level. Miguel J. Bagajewicz [21] has expanded the energy savings horizons for the retrofit of crude fractionation units. He adopted the methodology to take the advantage of two facts: (a) Pinch-type calculations can be performed using operator type representations and (b) Processes like crude fractionation offer large flexibility in the operating/design parameters.

Badr Abdullah AL Riyani et al. [22] have carried out the retrofitting analysis of a fluid catalytic cracking plant using pinch analysis and showed the energy saving potential in the plant. Matijaseviae and Otmaeiae [23] have studied the heat exchanger network of a nitric acid plant using the pinch technology. They have found the possibility of reduction in requirements for cooling water and medium pressure steam. They have found that utility saving is associated with the replacement of three heat exchangers. Thus, energy consumption increases slightly but final result is reduction of energy cost with a payback period of 14.5 months. Zhaolin Gu et al. [24] have pointed out some improper heat exchanger settings and retrofit modifications by the process integration using pinch technology, studying the case of the five column alcohol distillation section, which is broadly used in new distilleries in China. Sung-Geun Yoon et al. [25] have retrofitted the heat exchanger network (HEN) for an industrial ethylbenzene plant by pinch analysis. They have achieved the alternative HEN by adding a new heat exchanger and changing operating conditions. It reduces the annual energy cost by 5.6%. In order to achieve it, the capital investment is necessary but the annual cost saving will be enough to recover the cost in less than one year. Sujo-Nava et al. [26] have presented a case study of the retrofit of a sour water network in a petroleum refinery. After modification, they have found that 83 % of freshwater and 52 % of energy can be saved.

Kaj-Mikael Björk and Roger Nordman [27] and Ebrahim Rezaei and Sirous Shafiei [28] have retrofitted the heat exchanger network problem with mathematical programming method combined with genetic algorithms. R. Bochenek and J.M. Jeżowski [29] have applied genetic algorithms approach for retrofitting heat exchanger network with standard heat exchangers.

5. ALTERNATIVE APPROACHES FOR RETROFITTING ANALYSIS

Jos L. B. van Reisen et al. [30] have presented a prescreening and decomposition method to analyze heat exchanger networks for retrofitting. They called the method as Path Analysis which selects and analyses fractions from the existing network, either by heuristics or by an algorithm. By comparison of all fractions, the critical parts of the network that should be adapted can be identified. The adaptations can be done independent of the remaining network. Thus according to them, Path Analysis enables a considerable reduction of the effort in retrofit design. They have applied Path Analysis to an aromatics case. They have found that solutions tend to be less complex, while the profitability is sometimes higher than that was expected from global analysis.

Asante and Zhu [31] have described a new automated procedure for retrofit heat exchanger network design which minimizes the modifications in the existing HEN. Asante and Zhu [32] have presented two stage, systematic and automatic method for the retrofit design of heat exchanger networks. The first stage is diagnosis the HEN bottleneck and MILP formulation is used to select a single modification which will best overcome the identified bottleneck. In the second stage, the HEN is optimized using non-linear optimization techniques to minimize the cost of additional surface area employed.

Jos L. B. van Reisen et al. [33] have presented a new targeting method for the retrofit of heat exchangers networks. It combines existing targeting and design methods for retrofit with the concept of zoning used in grassroots design. Zoning also includes practical aspects like functionality; lay-out and operability. They have adopted their zoning methodology for aromatics case. They have found that the retrofit design effort is significantly reduced compared to existing methods. Athier et al. [34] have presented two level approach for the automatic determination of the optimal retrofit of an existing heat exchanger network considering the placement/reassignment of existing exchangers to different process stream matches, their need for additional area, the placement of a new heat exchanger and the cost of stream re-piping. In the first stage optimization has been carried out using simulated annealing and in the second stage optimized by a NLP algorithm. They have illustrated their approach by two examples.

Brioness and kokossis [35] have extended the conceptual programming technology for retrofit design problems. They have discussed the HEAT and TAME model formulations and optimized as MILP problems. They have reported up to 40% improvements in several examples. Abbas et al. [36] have described a novel approach to the retrofit problem using constraint logic programming. They have found that in most of the case studies on which program was tested; the solutions were superior to others reported in the literature. X. X. Zhu et al. [37] have retrofitted heat exchanger network using heat transfer enhancement. As a result of HEN retrofit, additional surface area is required for some heat exchangers. There are a number of options to provide additional area, such as installing new shells or new units, adding new tubes to an existing bundle, etc. According to them, if heat transfer enhancement (HTE) is applied, additional area can be reduced significantly. This can result in a great reduction in capital cost and implementation time for modifications. They have demonstrated the new procedure using a case study.

Ma et al. [38] have proposed two step solution method based upon mathematical programming for heat exchanger network retrofit. In the first step HEN is optimized using constant approach temperature model. In the second stage, they have used MINLP model which takes into consideration of actual approach temperatures to finalize the HEN design. Varbano and Klemes [39] have presented simple heuristics based on heat exchanger network retrofit techniques, developed by Tjoe and Linnhoff and extended by Asante and Zhu. According to them, this approach is useful when the direct application of the classic network pinch concept and rules is not possible to implement. F. Nourai et al. [40] have addressed the problem of finding environmentally clean alternatives for retrofitting existing processes. They have applied their method to an existing local production facility as a case study and risk-based pollution prevention targets. F. S. Liporace et al. [41] have proposed an alternative procedure to retrofit an industrial plant based on a new heat exchanger network synthesis and evolution algorithm. According to them, first a lower bound for HEN total annual cost is determined and new HEN is synthesized using pinch design method. Then, a comparison between this HEN and the actual one is performed to search for structural similarities, forming the set of match constraints. Then after, a new HEN keeping those similarities is proposed. The comparisons among the three HENs indicate the recommended structural modifications. They have applied the proposed alternative to a case study and found that retrofit can be performed without many changes.

B. L. Yeap et al. [42] have carried out retrofitting analysis of crude oil refinery heat exchanger networks to minimize fouling while maximizing heat recovery**.** They have showed that, at both the exchanger and network levels, designing for maximum heat recovery using traditional pinch approaches results in a less efficient system over time due to fouling effects.

Igor Bulatov [43] has proposed an overall framework for the retrofit of a plate fin heat exchanger network and applied for the debottlenecking of a liquefied petroleum gas cold box. He has also incorporated pressure drop parameters into the optimization framework. Ozgur Korkmaz et al. [44] have retrofitted the coal-fired power plants with carbon capture in order to meet strict climate protection aims. Nordman and Berntsson [45] have presented the theory and concept of a graphical method for heat exchanger network retrofit. By employing the approach, one general result they predict is that the closer to the pinch the existing heaters/coolers are located, the higher potential for cost-effective retrofit. Nordman and Berntsson [46] have employed the graphical method for cost-effective heat exchanger network retrofit to two cases. In the first case, they have compared the calculations with the results from the graphical method; while in the second case, they have compared graphical method is compared with the earlier published results. In both the cases, they have found the possibility of heat recovery.

6. APPLICATION OF RETROFITTING TO AMMONIA PLANTS

Shah and Weisenfelder [47] have described computerized control of a single train, large capacity ammonia plant. They have employed the computer to perform supervisory, interfacing control for various control loops in the plant as well as periodic on-line and off-line optimization of the profit function. They have found that the economic benefits achieved with the use of computer control because of improved plant performance and profit, on a monthly basis, easily justified the cost associated with the computer. A. D. Stephens and R. J. Richards [48] have described steady state and dynamic analysis of an ammonia synthesis plant. According to them, the analysis help in (1) better understanding of the operation of the plant, (2) designing a simple experimental scheme for optimizing and (3) indicating criteria which ensures optimization never enters in inoperable regions.

Radgen [49] has carried out exergy analysis of the ammonia plant and the urea plant of the fertilizer complex. They have found that existing overall exergetic efficiency is 60 % which includes 68.83 % exergetic efficiency of ammonia plant and 87.89 % exergetic efficiency of urea plant. They have found that the possible improvements are mainly equipment based and not due to the unfavorable positioning or matching of individual unit.

Penkuhn et al. [50] have presented a model that enlarges the well-known linear optimization model for joint production planning problems. The model is based on thermodynamic equilibria calculations and therefore they have formulated as a non-linear optimization model. They have implemented the model with the help of process simulation system ASPEN PLUS and applied as an example to a real world ammonia synthesis plant. The results showed that it is possible to improve the operating margin of the AMV ammonia process. De Wit and Riezebos [51] have revamped a 25-year-old ammonia plant which resulted in a lower energy consumption and higher production capacity. Haitham M. S. Lababidi et al. [52] have studied the energy retrofit of the front end of the ammonia plant using recent advances in pinch technology. They have inspected the front end of the ammonia plant and combined it with pinch technology. Yao Wang et al. [53] have performed the total process energy integration in retrofitting an ammonia plant using modified pinch analysis. Panjeshahi et al. [54] have performed a retrofit study of an ammonia plant to improve the energy efficiency. They have applied the combined pinch and exergy analysis and found reasonable saving (15 %) in power consumption without the need for the new investment.

Singh [55] has discussed that more than 150 KBR technology based ammonia plants installed globally in the 1960-1980. In the plants, ammonia synthesis converter with an internal heat exchanger is used for energy recovery. He has found that these plants still consume high energy and one key reason for this inherent deficiency is that all the waste heat in the synthesis loop of these plants is recovered by preheating boiler feed water rather than by producing high pressure steam. Recovering waste heat by raising medium pressure steam or by only preheating BFW makes these plants inherently energy deficit. According to him, new proprietary KBR technology can now upgrade heat recovery synthesis loop by implementing a simple modification in the existing ammonia converter and incorporating a HP steam raising boiler in the synthesis loop. He has found that depending upon current specific configuration; plant energy consumption can be reduced by 0.18 to 0.30 Gcal/MT of Ammonia. Through cooperation with the plant owners in Russia, such an upgrade is planned to incorporate.

Nand and Goswami [56] have reviewed the developments in ammonia and urea industries and the energy conservation efforts. They have found that energy consumption was reduced from 12.48 GCal/MT in 1987-1988 to 8.97 GCal/MT in 2007-2008 for ammonia plant. Chavda and Prabhakaran [57, 58] have implemented the fundamentals of the pinch technology and synthesized the ammonia production plant using two methodologies (1) minimum temperature approach and (2) minimum flux approach. The parameter is then optimized using Genetic Algorithms. They have applied network pinch method and retrofitting analysis method to modify the ammonia production plant. They proposed the network pinch method to modify the plant under study and achieved 1.71 % reduction in total annual cost.

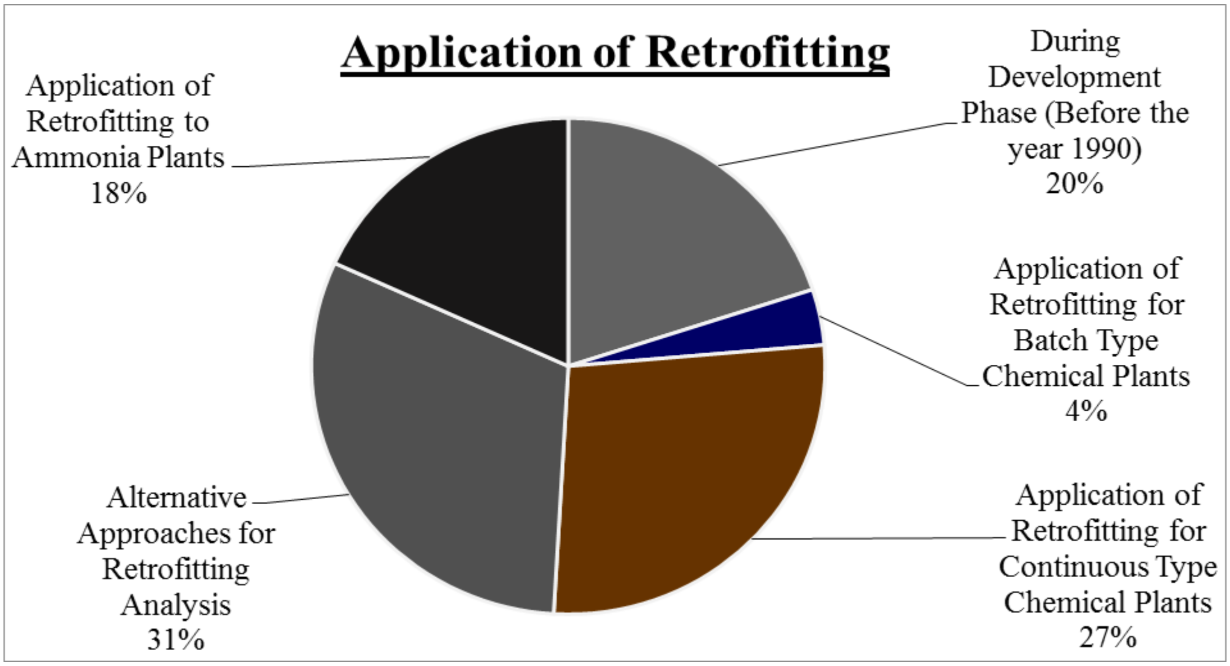
7. APPLICATION OF RETROFITTING

The above study of application of retrofitting can be summarized in Table 1. It is also represented by pie chart in Graph 1.

Table: 1 Application of Retrofitting

Sr. No.	Application of Retrofitting	Number of investigations as found in open literature.
1	During Development Phase (Before the year 1990)	11
2	Application of Retrofitting for Batch Type Chemical Plants	2
3	Application of Retrofitting for Continuous Type Chemical Plants	15
4	Alternative Approaches for Retrofitting Analysis	17
5	Application of Retrofitting to Ammonia Plant	10
Total		**55**

Graph 1 Application of Retrofitting



8. OUTCOME OF THE REVIEW

Form the investigations found in open literature on application of retrofitting analysis to Ammonia plant; it is observed that first two investigations are based on computerized control and behavioral pattern of ammonia plant. While the third one, describes the exergy analysis of fertilizer plant and found that exegetic efficiency of ammonia plant is critical which can be increased for overall increase in production of fertilizers. Fourth and fifth investigations are based on optimization of ammonia plant using non-linear model and inspection. Sixth investigation describes the front end analysis of ammonia plant. Seventh and eighth investigations are based on pinch analysis and pinch combined with exergy analysis. Ninth investigation describes the new technology for ammonia synthesis and last one describes the reviews of different modifications in ammonia plant and percentage saving associated with the modifications. There seems a possibility of combining pinch analysis with non-traditional optimization technique to retrofit the ammonia plant.

9. CONCLUSIONS

The necessity of implementation of retrofitting techniques has been understood in early 80's and various techniques for retrofitting analysis have been formulated in next decade. Application of retrofitting analysis after its development has been studied. Out of total fifty-five publications found in open literature, 58 % are related to the application of the retrofitting for continuous type chemical plant and alternative approaches for retrofitting analysis. Ammonia is the highly energy consuming plant. Therefore, the energy saving retrofit of the existing ammonia plant is essential. The present study shows that only 18 % of the total retrofitting application is in the field of retrofitting of ammonia plant. Yet more efforts in the direction of retrofitting the ammonia plant can conserve more energy.

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